

III. Debuncher

A. Function

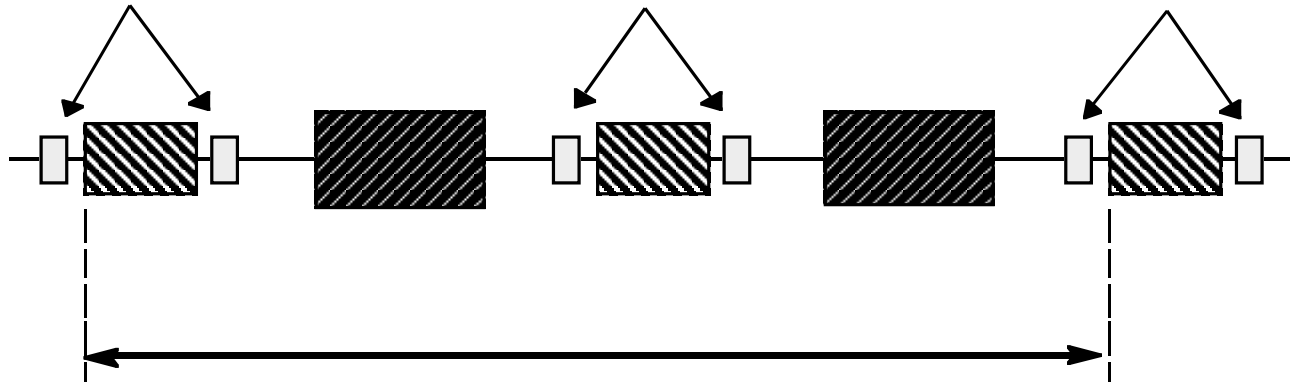
The purpose of the Debuncher is to accept pulses of antiprotons from AP-2 and reduce their momentum spread through RF bunch rotation and adiabatic debunching. This reduction in momentum spread is done to improve the Debuncher to Accumulator transfer because of the limited momentum aperture of the Accumulator at injection. In addition, ARF-1 and the stacktail momentum cooling system in the Accumulator are able to move the beam more efficiently when it has a small momentum spread. The Debuncher can make use of the time between Main Injector cycles to reduce the transverse beam size through betatron stochastic cooling. This greatly improves the efficiency of the Debuncher to Accumulator transfer. A momentum cooling system was later added which further reduces the momentum spread of the beam.

B. Lattice

The Debuncher 'ring' is a rounded triangle and is divided into 6 sectors numbered 10-60. Each sector contains 19 quadrupoles and 11 dipoles. Other magnetic devices include correction dipoles and sextupoles. There are three straight sections – 10, 30, and 50, which are located directly beneath service buildings AP10, 30 and 50 respectively. The even-numbered sectors serve as symmetric bridges between an odd-numbered sector and the next straight section. The straight sections are regions of low dispersion while the arcs are dispersive regions. A typical cell in the arcs is comprised of an F-quadrupole with similarly oriented sextupoles on either side followed by a dipole or drift region, then a D-quadrupole also surrounded by sextupoles of the same convention and another dipole or drift region (Figure 3.1). This is referred to as a “FODO” lattice. As is the case with straight sections in other Fermilab accelerator rings, the Debuncher straight sections contain an assortment of specialized components. The following devices populate straight section 10: the extraction kicker and septum for the D/A line, Schottky pickups (longitudinal and transverse), a beam current monitor, damper pickups and kickers and stochastic cooling pickup tanks. Stochastic cooling kickers are

found in the 30 region. The 50 area is home to the AP2 line injection devices and to all of the Debuncher's RF cavities.

One regular Debuncher FODO Cell, 8.865 meters



The numbering scheme is logical but not obvious at first glance. For example, D10Q is the first quadrupole in sector 10 (it is even in the middle of straight section 10) and is followed by D1Q2. Dipoles are numbered similarly – D1B16 is the dipole following D1Q16. Correction dipoles are labeled according to the quadrupole they proceed. Things get tricky in the even-numbered sections due to the mirror symmetry of the Debuncher lattice. The final quadrupole in D10 is D1Q19, and the next quad is D20Q (located in the center of the arc), followed by D2Q19, etc. Thus, in the direction of an antiproton beam, numbers increase in odd-numbered sectors and decrease in even-numbered sectors. The same general numbering scheme also holds true for the Accumulator, although there are fewer elements.

C. Power supplies

There are six major magnet strings in the Debuncher. The three quadrupole strings are powered by three supplies located in AP10, D:QD, D:QF, and D:QSS. D:QD powers all of the defocusing quads from DnQ6 to DnQ6 (with the exception of D6Q6). Recalling that the Debuncher lattice is FODO, D:QF, naturally, powers the focusing quadrupoles outside of the straight sections, from DnQ7 to DnQ7. D:QSS is the power supply for the

Debuncher quads in the straight sections, DnQ5 to DnQ5 (see figure 3.2), with the exception of D2Q5 and D4Q5. All magnets on the QSS bus are individually controlled by means of shunts. The Debuncher tune is changed by adjusting the D:QSn01 to D:QSn04 shunts in predetermined ratios (mults).

All of the dipoles save the correction trim dipoles are in series and are powered by D:IB, the Debuncher bend bus power supply. This supply is a very large PEI located in AP50 just inside of the west entrance. Three special quadrupoles are also powered by D:IB. These are the large quads at D2Q5, D4Q5, and D6Q6. At these locations, there must be a quadrupole in the lattice, but the small quadrupoles normally at these locations don't have a large enough aperture to accommodate both circulating and the injection or extraction beampipes. The solution was to install a large quadrupole with two beam pipes through the available aperture. The centered beam pipe is for circulating beam. The offset

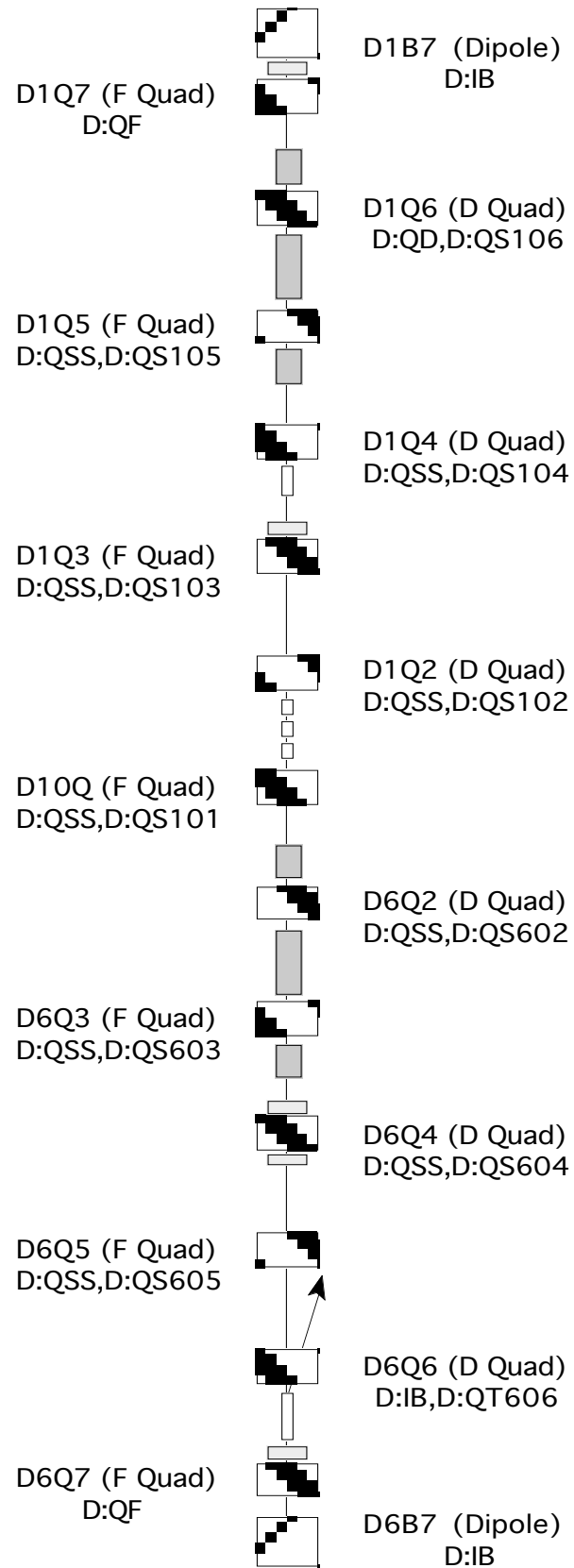


Figure 3.2 Debuncher 10 straight section

pipe is for injected/extracted beam, which sees a dipole field. In addition to being powered by D:IB, each of these magnets also has its own trim supply named D:QT205, D:QT405, and D:QT606 respectively. The large quadrupoles require much more current to produce the necessary field. Whereas D:QF and D:QD deliver about 240A of current, the combination of D:IB and the quadrupole trim supplies produces about 1,525A.

Additional shunts were added to the DxQ8,9,13,14,15,17,19 quadrupoles in the dispersive arcs during the Spring of 1995. These shunts, in combination with the shunts in the straight sections, are intended to be used as a " Γ_T jump". By ramping the shunts in the proper combination, the lattice (specifically the eta) can be altered to switch from the nominal lattice to one that improves the performance of the stochastic cooling. During development it was found that power supply regulation problems resulted in tune excursions and excessive beam loss so the shunts are not ramped operationally.

Sextupoles are included in the Debuncher lattice to provide chromaticity control. All of the sextupoles are powered in series on two separate buses by four supplies. Sextupoles on either side of an 'F' quad are powered by D:SEXF1 and D:SEXFV. Neither supply has sufficient current nor voltage to drive the entire string, so one supply provides the necessary voltage, while the other provides current regulation. D:SEXDI and D:SEXDV do the same thing for the 'D' sextupoles.

Correction dipoles have been placed around the Debuncher to provide fine orbit control of the beam. These elements are powered by 25 Amp bipolar supplies and have been strategically placed to provide position and angle control at the extraction and injection points of the Debuncher, stochastic cooling pick-ups and locations with tight apertures.

There isn't enough room in the lattice to place correction dipoles at every location that they are needed. There are three special devices that are used to provide a dipole bump to the beam. D:BS608 is a shunt on the D6B8 main dipole magnet. Shunting current around the dipole has the effect of a horizontal trim. This shunt is normally changed along with two correction dipoles to provide a three-bump at the Debuncher extraction septa. D:MS6Q12 and D:MSD6Q7 are motor controllers on the D6Q12 and D6Q7 quadrupoles that allow the magnets to be moved vertically. Changing the vertical position of the magnet will introduce a vertical dipole bump to the

beam due to quadrupole steering. These motor controllers are normally used with a vertical correction dipole to create a vertical three-bump at the Debuncher extraction kicker.

D. RF systems

Three radio frequency (RF) systems are employed in the Debuncher: DRF-1, DRF-2 and DRF-3. Table 3-1 summarizes the RF frequency, harmonic number, peak voltage and low level inputs for each system. Note that the same wide and narrow frequency band Digital to Analog Converters (DAC's) are common to all three systems.

System	Freq.	Harm.	Peak Voltage	Amplitude	Frequency
DRF-1	53.1 MHz	h=90	5.5 MV	DAC (D:R1LLDA) 164 card (D:R164AM)	DAC (D:R1LLFR) wide or narrow
DRF-2	2.36 MHz	h=4	500 V	DAC (D:R2LLAM)	DAC (D:R1LLFR) wide or narrow
DRF-3	2.36 MHz	h=4	800 V	DAC (D:R3LLAM) 164 card (D:R364AM)	DAC (D:R1LLFR) wide or narrow 164 card (D:R364FR)

Table 3.1 Debuncher RF systems

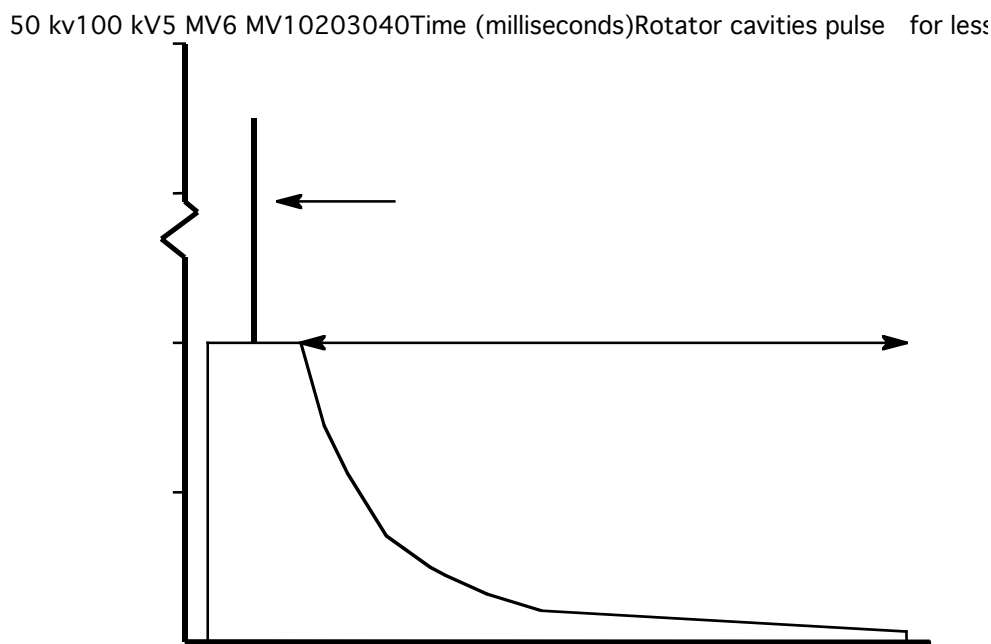
1. DRF-1

DRF-1 is a 53.1 MHz system (h=90) used for bunch rotation and adiabatic debunching of antiproton pulses injected into the Debuncher. Recall that bunch rotation in the Main Injector was done to reduce the phase space occupied by the antiprotons created at the target station. DRF-1 accepts the short (in time) pbar bunches coming from the target, rotates them in phase space resulting in bunches of antiprotons with a large time spread and a small momentum spread. The beam is then adiabatically (slowly) debunched over 60 milliseconds by lowering the RF voltage.

There are a total of eight DRF-1 cavities of two varieties: six so-called 'Rotators' and two 'Adiabatic' cavities. The six rotator RF cavities are able to operate at a peak voltage of approximately 1 MV each. In order to rapidly reduce their voltage, the RF drive signal is inverted just long enough for the fields in the cavity to be forced to zero. This rapid reduction in voltage is

necessary in order for the cavities to quickly pass through the range where they may multipactor, or spark. As the voltage on the six main cavities is reduced, the voltage on the other two cavities is slowly lowered from 100 kV to achieve debunching. These adiabatic cavities are of a somewhat different design to prevent multipactoring. The modifications consist mainly of a ceramic accelerating gap to isolate the beam pipe vacuum from the air in the cavity. This ceramic limits the peak voltage across the gap to about 150 kV. Figure 3.3 shows the total DRF-1 voltage during the debunching process.

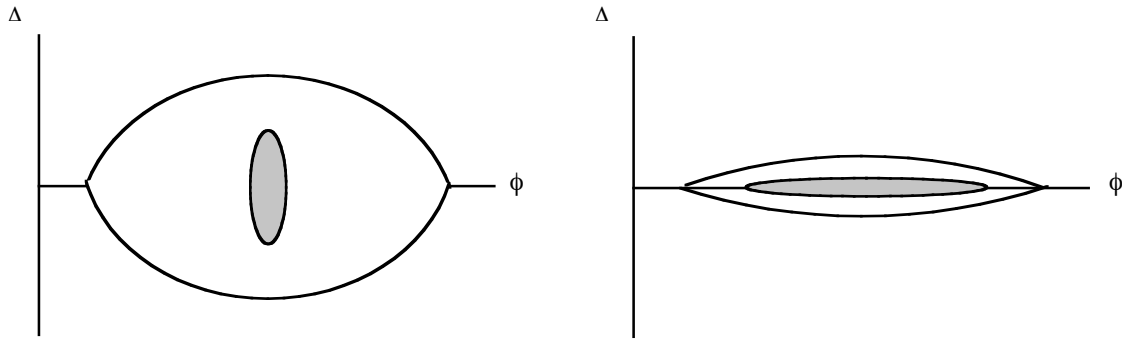
DRF1 is initially phase-locked to MIRF to provide for a bucket to bucket transfer. The 8 GeV secondary particles created at the target retain the same bunch structure as the 120 GeV protons. The DRF1 rotator cavities are



pulsed just before beam arrives in the Debuncher. When timed correctly the RF will reach peak voltage at the time beam is injected. The large bucket area creates a mismatch, as it is much larger than the phase space area of the beam. The rotator cavities only pulse for approximately 200 μ s (.2 ms) compared with the 36 ms that the adiabatics are on.

Because of the mismatch, the bunches rotate in the bucket as illustrated in figure 3.4. The rotator cavities are turned off after the bunches have rotated

p/pp/pMismatch between DRF1 bucket and bunch during bunch rotation Bunch growth during adiabatic debunching]



about 45° in phase space, they rotate an additional 45° during the adiabatic debunching process. Note that the rotator cavities pulse for only 200 μs but put out a collective 5.1 MV. The two adiabatic cavities are on for about 36 ms, but only put out a combined 100 kV before the voltage is gradually lowered.

The RF amplitude for DRF1 is divided into separate control for the rotator and adiabatic cavities. The adiabatics are normally controlled by a waveform generator (Camac 164) card but can also be run Continuous Wave (CW) with a DAC. The RF amplitude that the rotator cavities are pulsed to is controlled by a series of 6 DAC's, one for each cavity.

The frequency signal comes from one of two Voltage Controlled Oscillators (VCO's), a wideband VCO for studies, or a narrow band VCO used for normal operation. During stacking, the VCO is initially phase-locked to the Main Injector RF and stays at a fixed frequency. This frequency is generally set at the beginning of a running period and remains unchanged. For several years the DAC has been set to 53.10312 MHz. Since DRF1 is an $H=90$ system, this corresponds to a revolution frequency of 590,035 Hz. It is important that the beam injected into the Debuncher from the Main Ring has this revolution frequency as DRF1 and the momentum cooling will not work as well if the frequency varies significantly.

The bunch rotation efficiency provides a measure of how small the momentum spread of the antiprotons is shortly after DRF-1 is turned off. The parameter D:FFTEFF is derived by the pbar FFT from the Debuncher longitudinal schottky detector. Typical efficiencies are in the 75-85% range. Two parameters can be tuned to maximize the bunch rotation efficiency.

D:R1LLPS is the phase offset between the Main Injector and Debuncher low level RF and is tuned to optimize bucket to bucket transfer. D:R1LLMT is the master trigger time and controls when the DRF-1 rotator cavities are pulsed. By synchronizing the peak RF voltage (and bucket area) to the arrival of the beam, capture can be maximized. Qualitatively, the bunch rotation display on

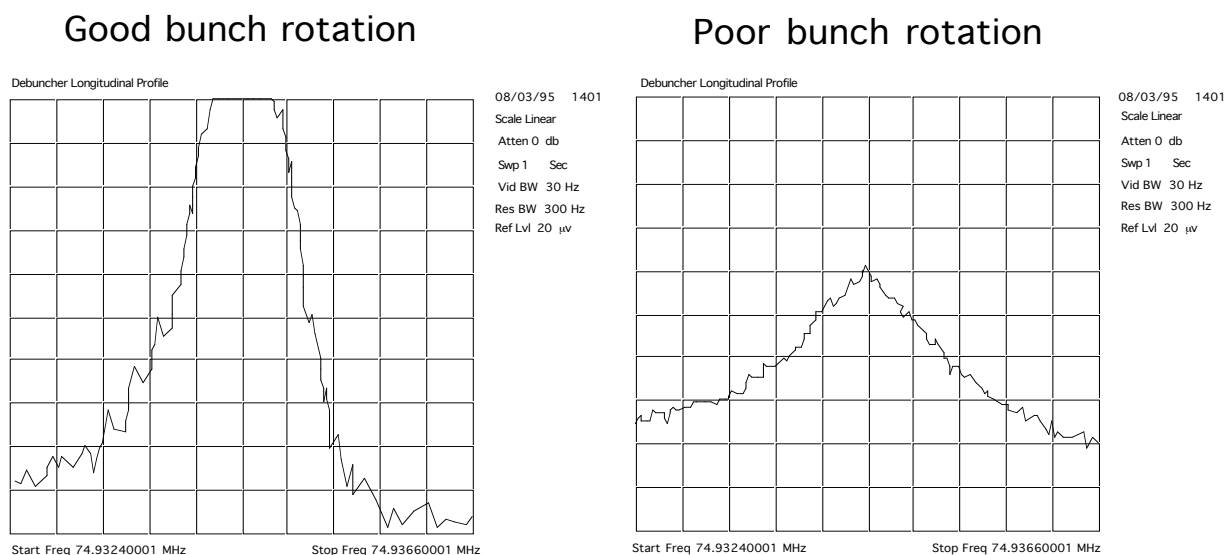


Figure 3.5 Debuncher spectrum analyzer displays

Cable Television (CATV) Pbar channel 30 gives a good indication of the rotation efficiency (see figure 3.5).

2. DRF-2

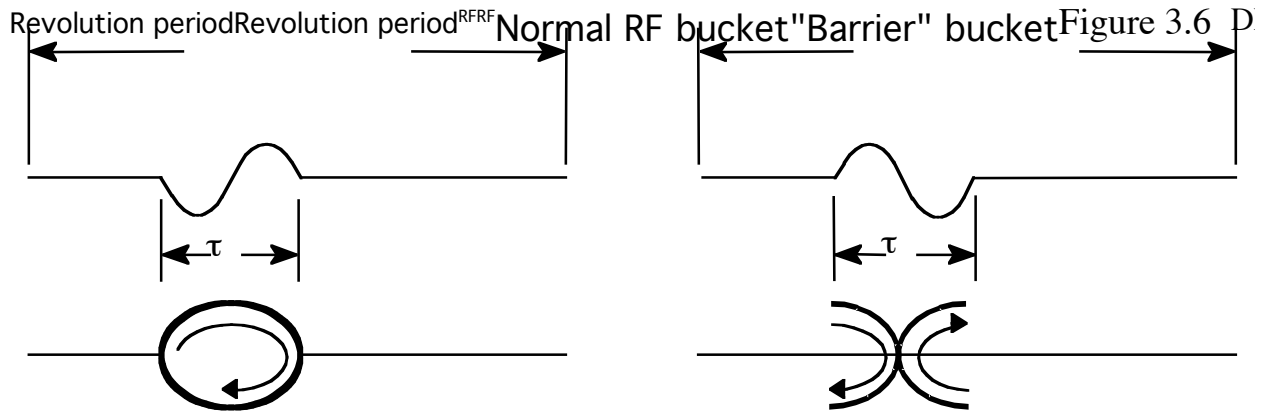
The Debuncher circumference is larger than that of the Accumulator (and the Booster) by 7.1%. The Debuncher 53 MHz harmonic number is 90, while the Accumulator's is 84. Debuncher to Accumulator transfer efficiency is optimized by maintaining a gap in the Debuncher beam. This is so that upon transfer the beam just fits around the circumference of the Accumulator. When properly timed, the Debuncher extraction kicker rise time occurs in the gap. The 200 nanosecond gap (compared to the revolution frequency of 1.69 μ s) is preserved by DRF-2, which forms a 'barrier bucket' that excludes particles from its interior. DRF-2 is timed to preserve a gap between the leading and trailing pbar bunches entering the Debuncher.

The period of the applied RF wave is one quarter of the Debuncher rotation period, making it an h=4 system. The nominal frequency is thus 2.36 MHz.

The gap electrodes are phased apart for one RF cycle during each revolution, then phased together for the remaining 3/4 revolution for zero effective voltage. The fact that the accelerating field is suppressed for part of each revolution is precisely the reason this type of radio frequency system is dubbed a 'suppressed bucket' RF system.

Referring to figure 3.6, a normal RF bucket keeps the particles within the bucket by accelerating low momentum particles and decelerating high momentum particles. In the barrier bucket example, the phase of the RF wave is shifted 180°. Higher momentum particles are accelerated upon entering the barrier bucket region, and lower momentum particles are decelerated which effectively excludes beam from the barrier bucket.

DRF-2 has a DAC that provides the amplitude program (D:R2LLAM). DRF-2's maximum voltage is approximately 500 V although it normally runs in the 200 - 400V range.



The same VCO used by DRF-1 is also used by DRF-2 (and DRF-3). The DRF-2 frequency (2.36 MHz instead of 53.1 MHz) is derived by dividing the output of the VCO by 22.5.

3. DRF-3

The third and final RF system found in the Debuncher is also an $h=4$ system. In this case, however, no buckets are suppressed. DRF-3 is used only as an aid during studies and is primarily used to move the beam to permit

full exploration of the Debuncher momentum aperture. It operates at up to 800 Volts.

Amplitude control for DRF-3 is provided by either a DAC or a 164 card, although the latter is rarely used. Frequency control is provided by either a 164 card or the same VCO's as DRF-1 and DRF-2 (again the 164 card is rarely used). As with DRF-2 the frequency from the VCO is divided by 22.5 to change the RF frequency from 53.1 MHz to 2.36 MHz. The wideband VCO is generally used with DRF-3 during studies to provide enough range to move the beam across the aperture.